# Evaluation and Comparison of Elliptical & Circular Hertz Contact Area for Bearing 6007, 6207, 6307 & 6407

**Ritesh Kumar Dewangan[1], Surendra Pal Singh Matharu[2]**
Department of Mechanical Engineering
[1]Rungta College of Engineering & Technology, Raipur (C.G.) India – 492001
[2]National Institute of Technology, Raipur (C.G.) India - 492001
E-Mails: [1] riteshdewangan12@gmail.com , [2]spmatharu123@gmail.com

***Abstract : Rolling element bearings are widely used in the industry and automobiles. Contact area between the races and balls plays an important role for the formation of elastohydrodynamic lubricant film. Formation of elastohydrodynamic lubricant film is the deciding factor for the life of the bearing. To increase the life it is important to maintain the lubricant film between the ball and races. Hertz has given the idea to calculate the contact area. Aim of this present paper is to calculate the elliptical and circular contact area for the rolling element bearing 6007, 6207, 6307 & 6407 at different load. And comparison is also made for elliptical and circular contact area.***

**Keywords: Rolling element bearing, Elastohydrodynamic lubricant film, Hertz contact area, Elliptical contact area, Elliptical Parameter, Complete elliptical integral of second kind.**

## I. Introduction

Hertz derived an analytical model for concentrated contact between two isotropic, homogeneous, linear elastic solids with smooth surfaces. When the solids are pressed together with a normal force Q to the surfaces, an approximately elliptic or circular contact area is formed. The elliptical and circular contact area for the rolling element bearing is calculated by Hertz contact theory [1-4]. This calculated area is used for the measurement of lubricant film thickness by using the analogy of electrical resistivity of lubricant [5-9], which is not included in this paper. The elliptical and circular contact area has been calculated here for the bearing 6007, 6207, 6307 & 6407. The variation of contact area with load is analysed here.

## II. Method & Calculation

### Calculation of Elliptical Area

According to Hertz theory of elastic elliptic contact equivalent radius can be calculated as:

$$\frac{1}{R_x} = \frac{1}{r_{ax}} + \frac{1}{r_{bx}}, \quad \frac{1}{R_y} = \frac{1}{r_{ay}} + \frac{1}{r_{by}} \quad \& \quad \frac{1}{R} = \frac{1}{R_x} + \frac{1}{R_y}$$

And the Semi minor & major axis can be calculated as:

$$a_i = \left[\frac{6\varepsilon QR}{\pi k E^*}\right]^{\frac{1}{3}} \qquad b_i = \left[\frac{6k2\varepsilon QR}{\pi E^*}\right]^{\frac{1}{3}}$$

where

$$\varepsilon = 1 + \left(\frac{q_a}{\alpha}\right), \quad q_a = \left(\frac{\pi}{2}\right) - 1, \quad \alpha = \frac{R_y}{R_x} \quad \& \quad k = (\alpha)^{(2/\pi)}$$

$$\frac{1}{E^*} = \frac{1-\nu_1^{\,2}}{E_1} + \frac{1-\nu_2^{\,2}}{E_2}$$

So, the elliptical area can be calculated as:

$a_1 = \pi \times a_i \times b_i$ & $a_2 = \pi \times a_i \times b_i$

In Table 1 useful dimensions are given, which has been used for the calculation of elliptical contact area.

**Table 1: Dimensions of Bearing**

| Bearing | Inner Race (mm) | | | Outer Race (mm) | | |
|---|---|---|---|---|---|---|
| | $r_{ax}$=$r_{ay}$ | $r_{bx}$ | $r_{by}$ | $r_{ax}$=$r_{ay}$ | $r_{bx}$ | $r_{by}$ |
| 6007 | 4.25 | 20 | -4.42 | 4.25 | -28.5 | -4.42 |
| 6207 | 5.75 | 21 | -5.98 | 5.75 | 32.5 | -5.98 |
| 6307 | 6.75 | 22 | -7.02 | 6.75 | 35.5 | -7.02 |
| 6407 | 10.75 | 23 | -11.18 | 10.75 | 44.5 | -11.18 |

On the basis of above formula, different parameter for elliptical area has been calculated for the Bearing 6007 and it is tabulated in the given table.

**Bearing 6007**

Using the dimensions given for bearing 6007 in Table 1, different parameters for the elliptical contact area is evaluated and tabulated in Table 2.

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**Table 2: Parameters Calculated for Elliptical Contact Area**

| PARAMETERS | INNER RACE | OUTER RACE |
|---|---|---|
| $1/R_x$ | 0.2853 | 0.2 |
| $1/R_y$ | 0.009 | 0.009 |
| $R_x$ | 3.51 | 4.99 |
| $R_y$ | 110.5 | 110.5 |
| $1/R = (1/R_x)+(1/R_y)$ | 0.2943 | 0.2093 |
| R | 3.4 | 4.78 |
| $\alpha = R_y / R_x$ | 31.53 | 22.12 |
| $k = (\alpha)^{(2/\pi)}$ | 9 | 7.18 |
| $q_a=(\pi/2)-1$ | 0.57 | 0.57 |
| $\varepsilon = 1 + (q_a / \alpha)$ | 1.02 | 1.03 |
| $E^*(N/mm^2)$ | 206900 | |

Now, the Elliptical contact area is tabulated below.

**Table 3: Elliptical Contact Area for Bearing 6007**

| RACE | Q (N) | $a_i$ | $b_i$ | $a_1$ & $a_2$ |
|---|---|---|---|---|
| Inner | 1000 | 0.1525 | 1.3723 | 0.6576 |
| Outer | 1000 | 0.1847 | 1.3263 | 0.7696 |

**Calculation of Circular Area**

According to Hertz theory of elastic circular contact:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \qquad \frac{1}{E^*} = k_1 + k_2 \;\&\; a = \left[\frac{3QR}{4\,E^*}\right]^{1/3} \qquad (1)$$

where

$$k_1 = \frac{1-\nu_1{}^2}{E_1} \qquad \& \qquad k_2 = \frac{1-\nu_2{}^2}{E_2}$$

Applying this theory for rolling element bearing, we have

$$a_i = \left[\frac{3Q(k_1+k_2)r_i r}{4(r_i+r)}\right]^{1/3} \;\&\; a_o = \left[\frac{3Q(k_1+k_2)r_o r}{4(r_o-r)}\right]^{1/3} \qquad (2)$$

$$a_1 = \pi(a_i)^2 \qquad \& \qquad a_2 = \pi(a_o)^2 \qquad (4)$$

In Table 4 useful dimensions are given, which has been used for the calculation of circular contact area.

**Table 4: Dimensions of Bearing**

| BEARING | $r_i$ (mm) | $r_o$ (mm) | R (mm) |
|---|---|---|---|
| 6007 | 20 | -28.5 | 4.25 |
| 6207 | 21 | -32.5 | 5.75 |
| 6307 | 22 | -35.5 | 6.75 |
| 6407 | 23 | -44.5 | 10.75 |

On the basis of above formula, different parameter for circular area has been calculated for the Bearing 6007 and it is tabulated in the Table 5.

**Bearing 6007**

Data given in Table 4 is used for the calculation of parameters used in the evaluation of circular contact area and is shown in the Table 5.

**Table 5: Parameters calculated for Circular Contact Area**

| PARAMETERS | |
|---|---|
| d | 8.50 |
| r = d/2 | 4.25 |
| $r_i = r_{bx}$ | 20.00 |
| $r_o = r_{bx}$ | -28.50 |
| $k_1 = k_2$ | 0.000004398 |

Now, the Circular contact area is tabulated below.

**Table 6: Circular Contact Area for Bearing 6007**

| Q (N) | $a_i$ | $a_i$ | $a_1$ | $a_2$ |
|---|---|---|---|---|
| 1000 | 0.2849 | 0.3206 | 0.25499 | 0.3229 |

**III. Graphical Representation**

Elliptical contact area for inner race and outer race for bearing 6007, 6207, 6307 & 6407 is analysed with load and is shown in Figure (1-4).

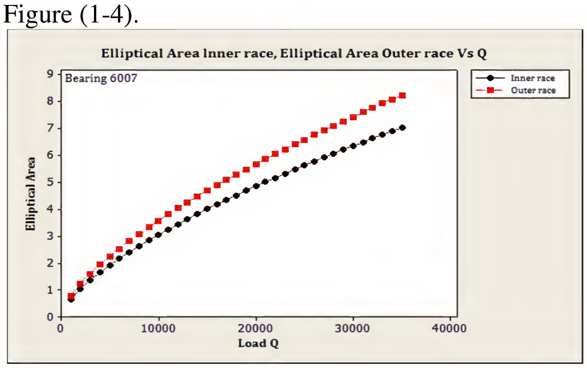


**Figure 1: Bearing 6007**

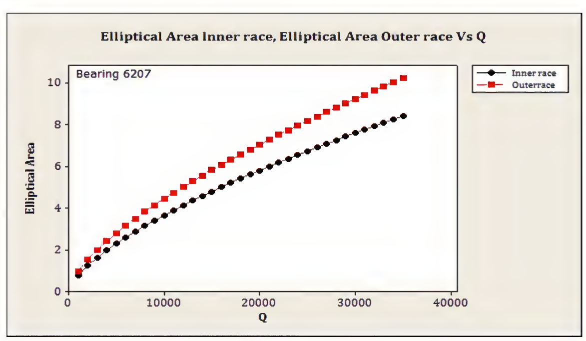


**Figure 2: Bearing 6207**

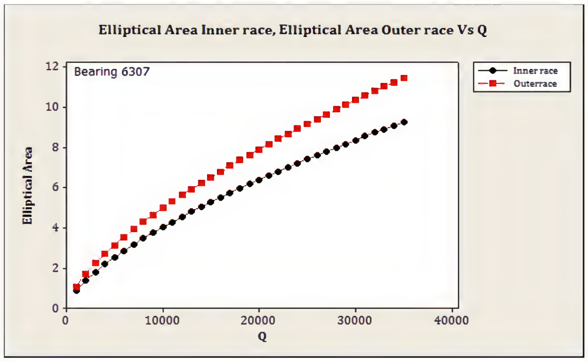


**Figure 3: Bearing 6307**

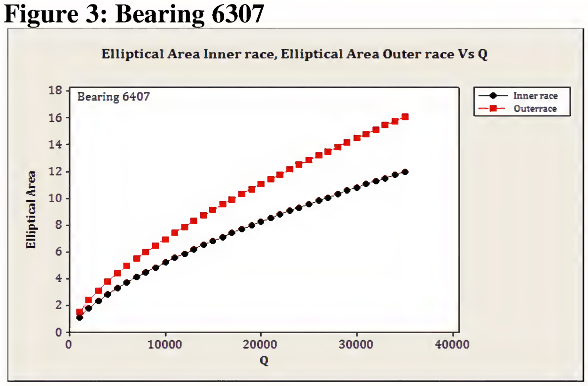


**Figure 4: Bearing 6407**

Above figure shows at the outer race elliptical contact area is more than the inner race.

Circular contact area for inner race & outer race for bearing 6007, 6207, 6307 & 6407 is shown in Figure (5-8).

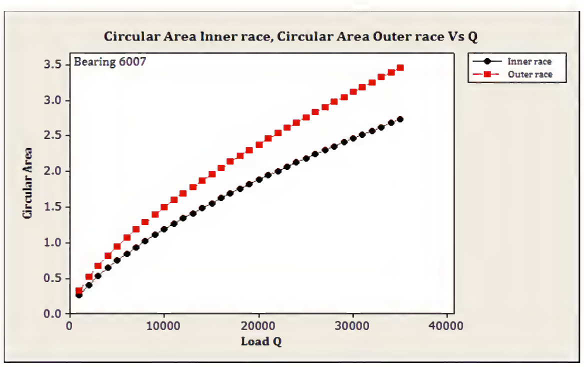


**Figure 5: Bearing 6007**

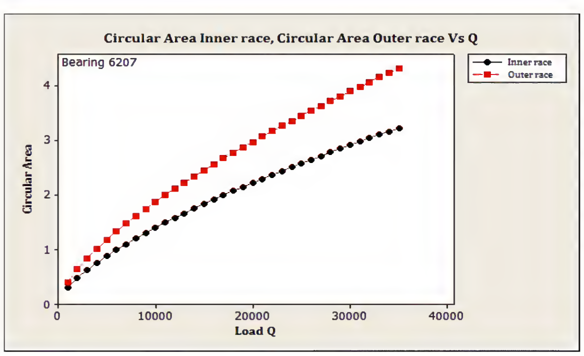


**Figure 6: Bearing 6207**

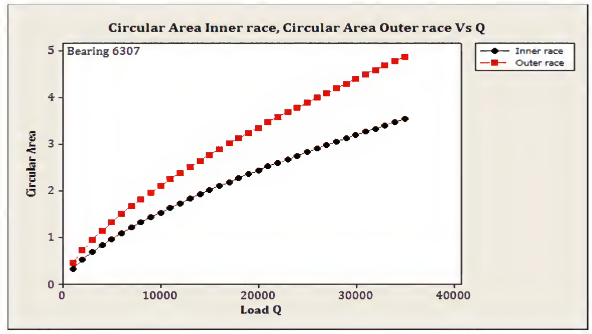


**Figure 7: Bearing 6307**

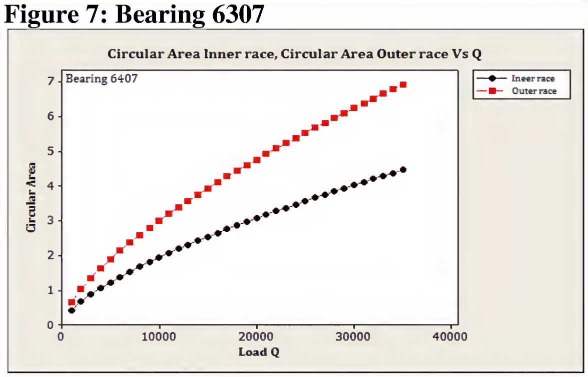


**Figure 8: Bearing 6407**

Here also it is found that the circular contact area is more for outer race than the inner race.

Figure (9-12) shows the elliptical and circular contact area for inner race and outer race for bearing 6007, 6207, 6307 & 6407.

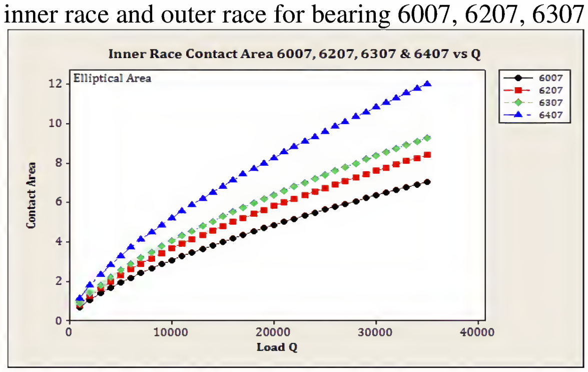


**Figure 9: Elliptical Contact Area at inner race for Bearing 6007, 6207, 6307 & 6407**

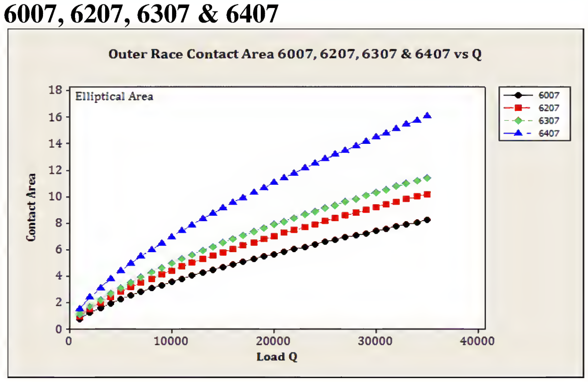


**Figure 10: Elliptical Contact Area at outer race for Bearing 6007, 6207, 6307 & 6407**


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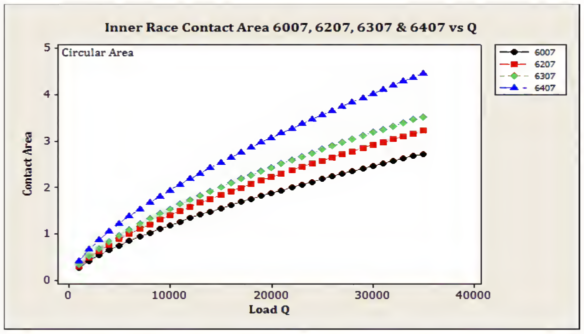


**Figure 11: Circular Contact Area at inner race for Bearing 6007, 6207, 6307 & 6407**

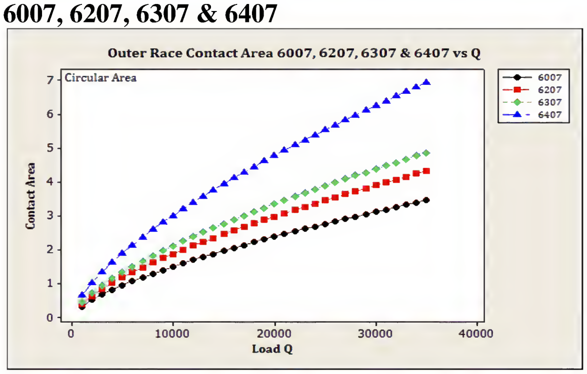


**Figure 12: Circular Contact Area at outer race for Bearing 6007, 6207, 6307 & 6407**

## RESULT

It is clear from the graph the contact area is increasing with increase in load. The elliptical and circular contact area for the load 1000N for all four bearing is tabulated below.

**Table 7: Elliptical & Circular Contact Area for Bearing 6007, 6207, 6307 & 6407**

| Bearing | Elliptical Area (mm$^2$) | | Circular Area (mm$^2$) | |
|---|---|---|---|---|
| | Inner Race | Outer Race | Inner Race | Outer Race |
| 6007 | 0.6576 | 0.7696 | 0.2549 | 0.3229 |
| 6207 | 0.7869 | 0.9554 | 0.3018 | 0.4038 |
| 6307 | 0.8657 | 1.0708 | 0.3302 | 0.4542 |
| 6407 | 1.1211 | 1.5032 | 0.4168 | 0.6472 |

## CONCLUSION

In Figure(1-4), variation of elliptical area for inner race and outer race are represented. It is clear from figure that the elliptical contact area is more for outer race than the inner race. And both the area is increasing with increase in load.

In the same way Figure(5-8), shows that the circular contact area is more for outer race than the inner race. And both the area is increasing with increase in load.

From Figure(9-12), it can be concluded that at particular load the inner race & outer race contact area is higher for higher bearing number. And both the area increases as the load increases.

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## Nomenclature

$k$ - Elliptical Parameter
$Q$ - Load
$a_i$ - Radius of contact ellipse in x-direction (mm)
$b_i$ - Radius of contact ellipse in x-direction (mm)
$a_1$ - Hertzian Contact Area at inner race (mm$^2$)
$a_2$ - Hertzian Contact Area at outer race (mm$^2$)
$\alpha$ - Radius ratio
$r_{ax}$ - Radius of ball wrt x-axis
$r_{ay}$ - Radius of ball wrt y-axis
$r_{bx}$ - Radius of race wrt x-axis
$r_{by}$ - Radius of racel wrt y-axis
$R_x$ - Equivalent radius of ball & race wrt x-axis
$R_y$ - Equivalent radius of ball & race wrt y-axis
$R$ - Overall equivalent radius
$\varepsilon$ - Complete elliptical integral of second kind
$q_a$ - Constant
$a_i$ - Radius of deformation between inner race and ball (mm)
$a_o$ - Radius of deformation between outer race and ball (mm)
$a_1$, $a_2$ - Contact area (mm$^2$)
$r_i$ - Outer radius of inner race (mm)
$r_o$ - Inner radius of outer race (mm)
$r$ - Radius of ball (mm)
$k_1$, $k_2$ - Constant $= 4.398X10^{-6}$ mm$^2$/N
$\nu_1$, $\nu_2$ - Poission's ratio for the material of ball & race ($\nu_1 = \nu_2 = 0.3$)
$E_1$, $E_2$ - Modulus of elasticity for the material of ball & race ($E_1 = E_2 = 206900$ N/mm$^2$)